

TITLE

DEVICES WITHOUT CURRENT CROWDING EFFECT AT THE FINGER'S ENDS

BACKGROUND OF THE INVENTION

Field of the Invention:

5 The present invention relates to an ESD protection device and particularly to an ESD protection device eliminating ESD current crowding events, so that a higher ESD level may be achieved under MM ESD testing.

Description of the Prior Art:

10 ESD damage has become one of the main reliability concerns facing IC (integrated circuit) products. Particularly, when scaled down to the deep sub-micron regime and the thinner gate oxide, the MOS become more vulnerable to ESD stress. For general industrial specifications, the
15 input and output pins of IC products must sustain HBM (Human-Body-Model) ESD stress of over 2000V and MM (Machine-Model) ESD stress of over 200V. Therefore, ESD protection circuits must be placed around the input and output (I/O) pads of the IC to protect IC against the ESD stress.

20 ESD protection devices are frequently drawn with large device dimensions and realized by finger-type layout to save total layout area. The layout top views and cross-sectional views of the prior arts to improve the ESD level of ESD protection devices by layout method are shown in FIG. 1A and
25 1B. It is formed on a P silicon substrate 11 and includes a STI (shallow trench isolation) 13 enclosing an active region 12, a P guard ring 14 enclosing the STI 13, two gates 15, each composed of polysilicon layer 151, gate oxide 152 and

spacers 153, and N drain and source region 161 and 162 placed in between and on the outer sides of the gates 15. The gates, source region, and body are typically connected to the ground while the drain region is connected to the input/output pad. The fundamental theorem of ESD protection design is based on the mechanisms of the MOS and the parasitic lateral n-p-n bipolar (BJT) under high current, and high field conduction. FIG. 2A and 2B are sectional views and an equivalent circuit of a NMOS transistor, with the drain 22 as the collector, substrate 21 as the body and source 23 as the emitter. During ESD stress, high field at the drain causes the N+ to P substrate junction to enter an avalanche breakdown condition, generating excessive electron-hole pairs. The current of the electron-hole pairs forward biases the substrate-source (PN junction), and the voltage drop across the substrate resistances increase the BE junction voltage of the parasitic BJT which is triggered to generate the snapback region in its I-V curves, as shown in FIG. 3. Thus, the parasitic BJT turns on to and bypass the ESD current.

FIG. 4A and 4B are top and sectional views of another conventional ESD protection device, a gate grounded NMOS. With comparison to the ESD protection device in FIG. 1A and 1B, it is noted that the bulk substrate resistance of the BB' region is much larger than that of the AA' region. This allows the parasitic BJT of the BB' region to turn on faster than that of the AA' region with higher collector current to bypass the ESD current and spread through the BB' region. The parasitic BJT of the BB' region can provide larger effective area than the AA' region to discharge the ESD

current, therefore it may have a high HBM ESD robustness. However, under MM ESD zapping, the drain node conductivity with higher peak currents of 3~4 Amps (for 200V MM ESD stress) often cause ESD damage at the corner or finger's end regions. The cause of damage is MM ESD current 3 or 4 times higher through an extremely small resistance than the HBM ESD current. Although the resistance of the AA' region is smaller than that of the BB' region, the breakdown current (due to ESD zapping at the drain) of the drain to substrate junction at the AA' region is still high enough to forward bias and to turn on the parasitic BJT at the AA' region, before turning on the parasitic BJT at the BB' region. Thus, an excess of current crowds around the AA' region and causes device failure at this region. Such damage is commonly shown in photographic training materials used in ESD protection design training courses.

SUMMARY OF THE INVENTION

The object of the present invention is to provide an ESD protection device eliminating ESD current crowding events to achieve a higher ESD level under MM ESD testing.

The present invention provides a first ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, a second gate disposed on a first side of the first gate and near the first end of the first gate, and a first and second doping region on the first and a second side of the first gate, and coupled to a second and the first node

respectively, wherein the first doping region has a first gap under the second gate.

The present invention provides a second ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, a second gate disposed on a second side of the first gate and near the first end of the first gate, and a first and second doping region on a first and the second side of the first gate, and coupled to a second and the first node respectively, wherein the second doping region has a first gap under the second gate.

The present invention provides a third ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, and a first and second doping region on the first and a second side of the first gate, and coupled to a second and the first node respectively, wherein the first doping region has a first gap near the first end of the first gate.

The present invention provides a fourth ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, and a first and second doping region on the first and a second side of the first gate, and coupled to a second and

the first node respectively, wherein the second doping region has a first gap near the first end of the first gate.

5 The present invention provides a fifth ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, and a first and second doping region on the first and a second side of the first gate, and coupled to a second and
10 the first node respectively, wherein the isolation region protruding into the first doping region near the first end of the first gate.

The present invention provides a sixth ESD protection device comprising a substrate, an isolation region on the
15 substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, and a first and second doping region on the first and a second side of the first gate, and coupled to a second and
20 the first node respectively, wherein the isolation region protruding into the second doping region near the first end of the first gate.

The present invention provides a seventh ESD protection device comprising a substrate, an isolation region on the
25 substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, and a first and second doping region on the first and a second side of the first gate, and coupled to a second and
30 the first node respectively, wherein the isolation region

has a first portion under the first end of the first gate protruding into both the first and second doping region.

5 The present invention provides an eighth ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, a first and second doping region on the first and a second side of the first gate, and coupled to a second and the first node respectively, and a third doping region disposed under the first and second doping region and near the first end of the first gate, having a doping concentration lower than that of the first and second doping region.

10 The present invention provides a ninth ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, a first and second doping region on the first and a second side of the first gate, and coupled to a second and the first node respectively, and a first well disposed under the first doping region and near the first end of the first gate.

20 The present invention provides a tenth ESD protection device comprising a substrate, an isolation region on the substrate, enclosing an active region, a first gate having a first and second end overlapping the isolation region to stretch over the active region, and coupled to a first node, and a first and second doping region on the first and a second side of the first gate, and coupled to a second and

30

the first node respectively, and wherein the first gate protruding into the first doping region so that, in the first doping region, a width of a center portion is larger than those of portions near the first and second end of the first gate.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings, given by way of illustration only and thus not intended to be limitative of the present invention.

FIG. 1A and 1B are top and sectional views of a conventional ESD protection device.

FIG. 2A and 2B are sectional views and an equivalent circuit of a NMOS transistor.

FIG. 3 is a diagram showing a relation between the current and breakdown voltage of a NMOS transistor.

FIG. 4A and 4B are top and sectional views of another conventional ESD protection device.

FIG. 5A and 5B are top and sectional views along a line AA' of an ESD protection device according to a first embodiment of the invention.

FIG. 6A and 6B are top and sectional views along a line AA' of an ESD protection device according to a second embodiment of the invention.

FIG. 7A and 7B are top and sectional views along a line AA' of an ESD protection device according to a third embodiment of the invention.

FIG. 8A and 8B are top and sectional views along a line AA' of an ESD protection device according to a fourth embodiment of the invention.

5 FIG. 9A and 9B are top and sectional views along a line AA' of an ESD protection device according to a fifth embodiment of the invention.

FIG. 10A and 10B are top and sectional views along a line AA' of an ESD protection device according to a sixth embodiment of the invention.

10 FIG. 11A and 11B are top and sectional views along a line AA' of an ESD protection device according to a seventh embodiment of the invention.

15 FIG. 12A and 12B are top and sectional views along a line AA' of an ESD protection device according to an eighth embodiment of the invention.

FIG. 13A and 13B are top and sectional views along a line AA' of an ESD protection device according to a ninth embodiment of the invention.

20 FIG. 14A and 14B are top and sectional views along a line AA' of an ESD protection device according to a tenth embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

First Embodiment

25 FIG. 5A and 5B are top and sectional views along a line AA' of an ESD protection device according to a first embodiment of the invention. It includes a P silicon substrate 51, STI (shallow trench isolation) 52, a P guard ring 50 enclosing the STI 52, gates 531 and 532, dummy gates 541~544, and N drain and source region 551 and 552. The STI

52 is on the substrate 51 and encloses an active region 56. The gates 531 and 532 have two ends overlapping the STI 52 to stretch over the active region 56, and are coupled to ground or a pre-driver. The dummy gates 541~544 are
5 disposed on a common side and near each end of the gates 531 and 532. Each of the dummy gates 541~544 has one end overlapping the STI 52. The drain and source region 551 and 552 are disposed in between and on outer sides of the gates 531 and 532, and coupled to a pad and ground, respectively.
10 The drain region 551 has gaps 571~574 under the dummy gates 541~544. Each of the gates 531 and 532, and dummy gates 541~544 includes a conducting layer 581 made of polysilicon, an oxide layer 582 made of silicon oxide under the conducting layer 581 and spacers 583 made of silicon oxide
15 adjacent to the conducting layer 581 and oxide layer 582.

In the first embodiment, the base width of the parasitic BJT is directly related to the gate length of the NMOS and the longer channel transistor will have a lower turned-on efficiency because of lower bipolar efficiency.

20 The dummy gates 541~544 at the AA' region are used to increase the base width of the parasitic BJT at the AA' region and decrease its turned-on efficiency. While the base width of the parasitic BJT at the BB' region is shorter than it is at the AA' region, the turned-on efficiency of
25 the BB' region can be successfully balanced. Therefore, the parasitic BJT at the BB' region will turn on sooner than it will at the AA' region, providing a larger bypass ESD current area than the AA' region and increasing the high MM ESD level. On the other hand, the HBM ESD level will not
30 decrease while dummy gates 541~544 are inserted into the

active region 56 under HBM ESD zapping because the bypass ESD current area is almost the same as the devices of the prior arts.

Second Embodiment

5 FIG. 6A and 6B are top and sectional views along a line AA' of an ESD protection device according to a second embodiment of the invention. With comparison to the ESD protection device shown in FIG. 5A and 5B, it is noted that the dummy gates 541~544 are disposed on the source region
10 552 so that the gaps 571~574 are located in the source region 552 in the ESD protection device of FIG. 6A and 6B. The ESD protection devices in FIG. 5A and 5B, and 6A and 6B have equal ESD performance.

Third Embodiment

15 FIG. 7A and 7B are top and sectional views along a line AA' of an ESD protection device according to a third embodiment of the invention. It includes a P silicon substrate 71, STI (shallow trench isolation) 72, a P guard ring 70 enclosing the STI 72, gates 731 and 732, and N drain
20 and source region 751 and 752. The STI 72 is on the substrate 71 and encloses an active region 76. The gates 731 and 732 have two ends overlapping the STI 72 to stretch over the active region 76, and are coupled to ground or a pre-driver. The drain and source region 751 and 752 are
25 disposed in between and on outer sides of the gates 731 and 732, and coupled to a pad and ground, respectively. The drain region 751 has gaps 741~744 near each end of the gates 731 and 732. The gaps 741~744 are formed by an implantation step compatible with a CMOS process, during which a mask
30 blocks the gaps 741~744 from N+ ions. Each of the gates 731

and 732 includes a conducting layer 781 made of polysilicon, an oxide layer 782 made of silicon oxide under the conducting layer 781 and spacers 783 made of silicon oxide adjacent to the conducting layer 781 and oxide layer 782.

5 The layout method of the third embodiment, increases the AA' region resistance and decreases parasitic BJT turning on efficiency, making it possible for ESD current to go through the BB' region under MM ESD zapping. Thus, the MM ESD current bypasses bigger areas and has a higher MM ESD
10 level than the device structures of prior arts. On the other hand, the HBM ESD level will not decrease as it will without N+ diffusion between the gates and drain contact at the AA' region. Moreover, the proposed layout method can also be applied to the PMOS to improve its ESD robustness.

15 **Fourth Embodiment**

FIG. 8A and 8B are top and sectional views along a line AA' of an ESD protection device according to a fourth embodiment of the invention. With comparison to the ESD protection device shown in FIG. 7A and 7B, it is noted that
20 the gaps 741-744 are located in the source region 752. The ESD protection devices in FIG. 7A and 7B, and 8A and 8B have equal ESD performance.

Fifth Embodiment

FIG. 9A and 9B are top and sectional views along a line
25 AA' of an ESD protection device according to a fifth embodiment of the invention. It includes a P silicon substrate 91, STI (shallow trench isolation) 92, a P guard ring 90 enclosing the STI 92, gates 931 and 932, and N drain and source region 951 and 952. The STI 92 is on the
30 substrate 91 and encloses an active region 96. The gates

931 and 932 have two ends overlapping the STI 92 to stretch over the active region 96, and are coupled to ground or a pre-driver. The drain and source region 951 and 952 are disposed in between and on outer sides of the gates 931 and 932, and coupled to a pad and ground, respectively. The STI 941~944 protrudes into the drain region 951 near each end of the gates 931 and 932. Each of the gates 931 and 932 includes a conducting layer 981 made of polysilicon, an oxide layer 982 made of silicon oxide under the conducting layer 981 and spacers 983 made of silicon oxide adjacent to the conducting layer 981 and oxide layer 982.

The layout method of the fifth embodiment, increases the AA' region resistances and decreases parasitic BJT turning on efficiency, making it possible for ESD current to go through the BB' region under MM ESD zapping. Thus, the MM ESD current bypasses bigger areas and has a higher MM ESD level than the device structures of prior arts. Conversely, the HBM ESD level will not decrease as STI is inserted between the gate and drain contact or below the gate at the AA' region. Moreover, the proposed layout method can also be applied to the PMOS to improve ESD robustness.

Sixth Embodiment

FIG. 10A and 10B are top and sectional views along a line AA' of an ESD protection device according to a sixth embodiment of the invention. With comparison to the ESD protection device shown in FIG. 9A and 9B, it is noted that the STI 941~944 protrudes into the source region 952. The ESD protection devices in FIG. 9A and 9B, and 10A and 10B have equal ESD performance.

Seventh Embodiment

FIG. 11A and 11B are top and sectional views along a line AA' of an ESD protection device according to a seventh embodiment of the invention. For the sake of clarity, the same elements in FIG. 11A and 11B, and 9A and 9B refer to the same symbols. The ESD protection device includes a P silicon substrate 91, STI (shallow trench isolation) 92, a P guard ring 90 enclosing the STI 92, gates 931 and 932, and N drain and source region 951 and 952. The STI 92 is on the substrate 91 and encloses an active region 96. The gates 931 and 932 have two ends overlapping the STI 92 to stretch over the active region 96, and are coupled to ground or a pre-driver. The drain and source region 951 and 952 are disposed in between and on outer sides of the gates 931 and 932, and coupled to a pad and ground, respectively. The STI 941~944 has portions under the gates 931 and 932 and near each end of the gates 931 and 932 protruding into both the drain and source region 951 and 952. Each of the gates 931 and 932 includes a conducting layer 981 made of polysilicon, an oxide layer 982 made of silicon oxide under the conducting layer 981 and spacers 983 made of silicon oxide adjacent to the conducting layer 981 and oxide layer 982.

The layout method of the fifth embodiment, increases the AA' region resistances and decreases parasitic BJT turning on efficiency, making it possible for ESD current to go through the BB' region under MM ESD zapping. Thus, the MM ESD current bypasses bigger areas and has a higher MM ESD level than the device structures of prior arts. Conversely, the HBM ESD level will not decrease as STI is inserted

between the gate and drain contact or below the gate at the AA' region.

Eighth Embodiment

FIG. 12A and 12B are top and sectional views along a
5 line AA' of an ESD protection device according to an eighth
embodiment of the invention. For the sake of clarity, the
same elements in FIG. 12A and 12B, and 5A and 5B refer to
the same symbols. The ESD protection device includes a P
silicon substrate 51, STI 52, a P guard ring 50 enclosing
10 the STI 52, gates 531 and 532, N drain and source region 551
and 552, and ESD implantation regions 591 and 592. The STI
52 is on the substrate 51 and encloses an active region 56.
The gates 531 and 532 have two ends overlapping the STI 52
to stretch over the active region 56, and are coupled to
15 ground or a pre-driver. The drain and source region 551 and
552 are disposed in between and on outer sides of the gates
531 and 532, and coupled to a pad and ground, respectively.
The ESD implantation regions 591 and 592 are N lightly doped
regions disposed under the drain and source region 551 and
20 552, and near each end of the gates 531 and 532. The doping
concentrations of the ESD implantation regions 591 and 592
are lower than those of the drain and source region 551 and
552. Each of the gates 531 and 532 includes a conducting
layer 581 made of polysilicon, an oxide layer 582 made of
25 silicon oxide under the conducting layer 581 and spacers 583
made of silicon oxide adjacent to the conducting layer 581
and oxide layer 582.

In the eighth embodiment, the junction covered by the
proposed ESD implantation has an increased junction
30 breakdown voltage, because it has a lighter doping

concentration across the p-n junction. The BB' region without covering the ESD implantation, however, has the original junction breakdown voltage, which is lower than the junction breakdown of the ESD implantation region. During the ESD stress, the junction the BB' region with the lowest junction breakdown voltage will be broken first to discharge the ESD current. As previously mentioned, the AA' region provides a larger bypass area and path for ESD current and has a high MM ESD level. On the other hand, the HBM ESD level will not decrease as the ESD implanted between the gate and drain contact or below the gate at the AA' region. This can also be applied to the PMOS to improve its ESD robustness.

Ninth Embodiment

FIG. 13A and 13B are top and sectional views along a line AA' of an ESD protection device according to an eighth embodiment of the invention. For the sake of clarity, the same elements in FIG. 13A and 13B, and 5A and 5B refer to the same symbols. The ESD protection device includes a P silicon substrate 51, STI 52, a P guard ring 50 enclosing the STI 52, gates 531 and 532, N drain and source region 551 and 552, and N wells 593 and 594. The STI 52 is on the substrate 51 and encloses an active region 56. The gates 531 and 532 have two ends overlapping the STI 52 to stretch over the active region 56, and are coupled to ground or a pre-driver. The drain and source region 551 and 552 are disposed in between and on outer sides of the gates 531 and 532, and coupled to a pad and ground, respectively. The N wells 593 and 594 are disposed under the drain region 551, and near each end of the gates 531 and 532. Each of the

gates 531 and 532 includes a conducting layer 581 made of polysilicon, an oxide layer 582 made of silicon oxide under the conducting layer 581 and spacers 583 made of silicon oxide adjacent to the conducting layer 581 and oxide layer
5 582.

In the ninth embodiment, the MOSFET at the AA' region has a lighter doping concentration (N well) than that of the original (N+) drain junction. Therefore, the junction covered by the proposed N well has an increased junction
10 breakdown voltage, because it has a lighter doping concentration across the p-n junction. However, the BB' region without inserting N well has the original junction breakdown voltage, which is lower than the junction breakdown of the AA' region with N well inserted. During
15 the ESD stress, the junction the BB' region with the lowest junction breakdown voltage will be broken first to discharge the ESD current. As previously mentioned, the AA' region provides a larger bypass area and path for ESD current and has a higher MM ESD level.

20 **Tenth Embodiment**

FIG. 14A and 14B are top and sectional views along a line AA' of an ESD protection device according to an eighth embodiment of the invention. For the sake of clarity, the same elements in FIG. 14A and 14B, and 5A and 5B refer to
25 the same symbols. The ESD protection device includes a P silicon substrate 51, STI 52, a P guard ring 50 enclosing the STI 52, gates 531 and 532, and N drain and source region 551 and 552. The STI 52 is on the substrate 51 and encloses an active region 56. The gates 531 and 532 have two ends
30 overlapping the STI 52 to stretch over the active region 56,

and are coupled to ground or a pre-driver. The drain and source region 551 and 552 are disposed in between and on outer sides of the gates 531 and 532, and coupled to a pad and ground, respectively. The gates 531 and 532 are bent at
5 an angle so that their center portions protrude into the drain region 551. Thus, the widths of the drain region 551 near the center portions of the gates 531 and 532 are smaller than those near each end of the gates 531 and 532. Each of the gates 531 and 532 includes a conducting layer
10 581 made of polysilicon, an oxide layer 582 made of silicon oxide under the conducting layer 581 and spacers 583 made of silicon oxide adjacent to the conducting layer 581 and oxide layer 582.

In the tenth embodiment, at the AA' region, the drain
15 contact to the poly edge space (DGS) is larger than the space at the BB' region, therefore the equivalent base spacing of the parasitic BJT device at the AA' region can be increased. With a wider base spacing, the BJT will have a lower turn-on speed and lower current gain. In this
20 structure, the turn-on efficiency of the parasitic BJT at the AA' region decreases. ESD current will be discharged through the parasitic BJT at the BB' region under MM ESD zapping. Thus, the MM ESD current effectively bypasses bigger areas and has a higher MM ESD level than the device
25 structures of the prior arts. Conversely, the HBM ESD level will not decrease and can also be applied to the PMOS to improve its ESD robustness.

In all the previously described embodiments, the layouts are also suitable for PMOS although NMOS is used as

an example. They are also suitable for stacked NMOS or PMOS in mixed voltage I/O circuits.

In conclusion, novel ESD protection device structures are proposed in this invention for application under MM ESD stress in sub-quarter-micron CMOS technology. The ESD discharging current path in the NMOS or PMOS device structure is changed by the proposed new structures, therefore the MM ESD level of the NMOS and PMOS can be significantly improved. In this invention, 6 kinds of new structures protect the lateral BJT at the AA' region from current crowding and to balance the turned on efficiency of the lateral BJT at the BB' region. The MM ESD current bypasses through the lateral BJT at the BB' region instead of the AA' region, and has a larger bypass area than the prior structures. The current crowding problem can be solved successfully, and have a higher MM ESD robustness. Moreover, these novel devices will not degrade the HBM ESD level and are widely used in ESD protection circuits.

The foregoing description of the preferred embodiments of this invention has been presented for purposes of illustration and description. Obvious modifications or variations are possible in light of the above teaching. The embodiments were chosen and described to provide the best illustration of the principles of this invention and its practical application to thereby enable those skilled in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the present invention as determined by the appended claims when interpreted in accordance with the

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breadth to which they are fairly, legally, and equitably
entitled.